

The Galactic Environments of Nearby Cool Stars

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Abstract

The definition of nearby star systems is incomplete without an understanding of the dynamical interaction between the stars and ambient interstellar material. The Sun itself has been immersed in the Local Bubble interior void for millions of years, and entered the outflow of interstellar material from the Scorpius-Centaurus Association within the past $\sim 10^5$ years. Heliosphere dimensions have been relatively large during this period. A subset of nearby stars have similar recent histories, and astrosphere properties are predictable providing ambient interstellar matter and stellar activity cycles are understood. The properties of astrospheres can be used to probe the interstellar medium, and in turn outer planets are more frequently immersed in raw interstellar material than inner planets.

Astrospheres of Nearby Stars

Interstellar matter (ISM) governs the interplanetary environment of nearby cool star systems since neutral interstellar gas penetrates stellar wind bubbles (astrospheres). In the case of the heliosphere (the solar wind bubble around the Sun), 98% (by number) of the diffuse gas in the heliosphere is interstellar gas. By analogy with the heliosphere, stellar astrospheres can be modeled by equating the ram pressure of the stellar wind (which depends on activity cycles) and the ram pressures of the surrounding interstellar cloud. Heliosphere models explain many observable particle populations and phenomena seen by spacecraft, such as the distribution and ionization of interstellar neutrals, the pickup ion and anomalous cosmic ray daughter products, and the distribution of interstellar dust (see Landgraf paper, this volume). Outer planets are more likely to be immersed in raw interstellar material than inner planets.

The interstellar pressure on an astrosphere is set by charged ISM components which are excluded from the astrosphere by the Lorentz force – interstellar ions (including those formed by charge exchange in the astropause regions), low energy cosmic rays, and the smallest interstellar dust grains. Astrosphere dimensions for several nearby G-stars have been estimated and are shown in the attached table (from Frisch 1993). For example, our nearest star the Sun has a heliosphere radius of ~ 120 AU, and a weak bow shock may

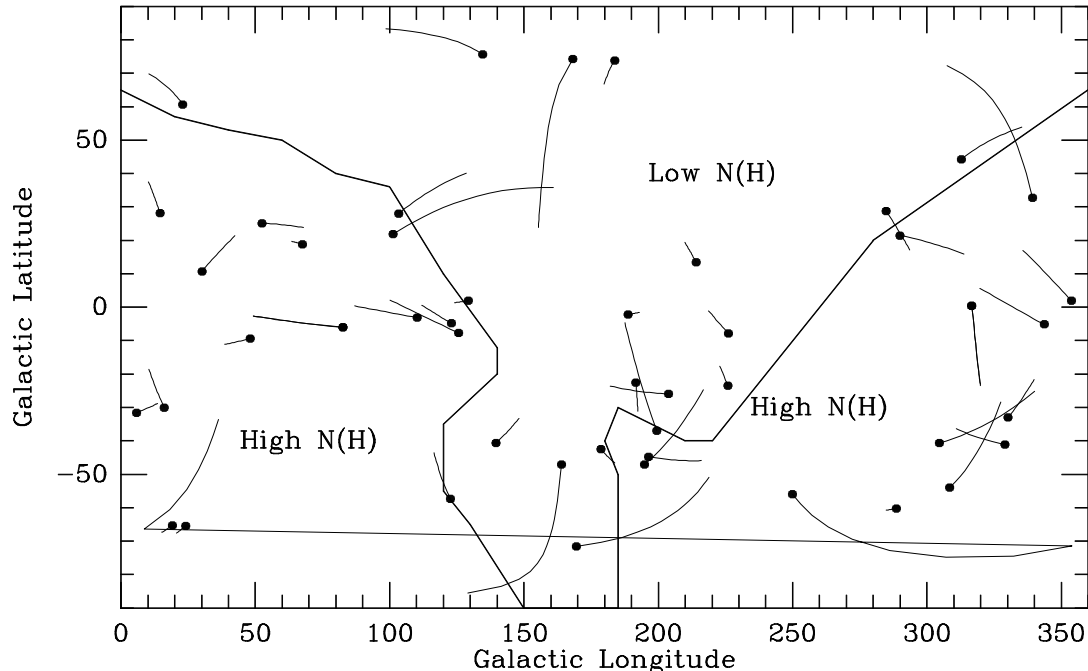


Figure 1: Space trajectories of bright stars within 10 parsecs, over timescales of $0.8 \cdot 10^5$ years. Dots are current star positions. Regions of high and low density interstellar matter are denoted, based on results from Genova et al. (1990, ApJ, v355, p150). Note that stars located in the galactic center hemisphere, and at low galactic latitudes, are more likely to be immersed in clouds yielding accretion of ISM onto planetary atmospheres.

be located at ~ 200 AU. Heliosphere properties vary with both ambient interstellar properties and with the solar activity cycle, of which the well-known Forbush decrease in cosmic-ray intensity is an example.

Local Interstellar Matter

We have a basic understanding of the properties of ISM within 25 pc of the Sun. The interstellar cloud surrounding the solar system is warm, partially ionized and low density ($T \sim 7000$ K, $n(\text{H}^0) \sim 0.22 \text{ cm}^{-3}$, $n(\text{H}^+) \sim 0.1 \text{ cm}^{-3}$ (e.g. Frisch et al. 1999). The relative cloud-Sun velocity is $\sim 26 \text{ km s}^{-1}$. The thumbprint of $100\text{--}200 \text{ km s}^{-1}$ interstellar shocks is apparent from the enhanced abundances of refractory elements observed in nearby ISM, resulting from interstellar grain destruction (Frisch et al. 1999). The distribution of nearby ($d < 30$ pc) interstellar material is highly asymmetric, with the bulk of material located in the galactic-center hemisphere and low galactic latitudes (see Fig. 1). Local ISM is structured, indicating inhomogeneous densities. If

a density clump of $n(\text{H}^\circ)=10 \text{ cm}^{-3}$ were embedded in the cloud surrounding the solar system and encountered by the Sun, the heliosphere radius would shrink to about 15 AU (from the current ~ 120 AU) and the heliopause would become unstable. The mass density of interstellar neutrals would increase from $\sim 1 \times 10^{-25}$ to $\sim 5 \times 10^{-24} \text{ g cm}^{-3}$ at the 1 AU location of the Earth after such an encounter, dramatically altering the Earth's interplanetary environment (see Zank and Frisch 1999). Outer planets are therefore more likely to be exposed to raw interstellar material than inner planets.

The outflow of interstellar material from the nearby Scorpius-Centaurus Association governs the galactic environment of the Sun and other nearby stars. This author believes that the Sun is immersed in the leading edge of a superbubble shell associated with the latest epoch of star formation in the Scorpius-Centaurus Association (Frisch 1998b). Velocities of nearby ISM clouds cluster about a vector motion consistent with a gas flow from the Scorpius-Centaurus Association. A bulk flow velocity in the LSR of -20 km s^{-1} from the direction $l=315^\circ$, $b=-3^\circ$ provides a better match to radial velocities of interstellar clouds observed towards nearby stars than does the LSR "standard" velocity frame. (This value for the LSR upwind direction depends on the value used for the solar apex motion; a recent apex velocity based on Hipparchos data yields an interstellar flow velocity of $V=-15 \text{ km s}^{-1}$, arriving from $l=344^\circ$, $b=-2^\circ$, Frisch 1999).

Paleoastrospheres

The historical astrosphere of a star can be predicted by comparing the stellar space trajectory with the distribution and motions of interstellar clouds. Space motions of stars can be extrapolated back in time for several million years. The dynamics of interstellar clouds are governed by star formation activity (for diffuse clouds) and spiral arm patterns (for molecular clouds). The ISM is highly structured, with tenuous hot plasmas and warm diffuse low density material both yielding large astrospheres (although the interplanetary environments differ for these two cases). Astrosphere properties can be predicted based on properties of interstellar clouds surrounding each star, and relative to space motions of the star and ISM. The following nearby stars are predicted to have astrospheres unchanged over the past several million years, with astropause radii $\sim 65\text{-}75$ AU, based on the space trajectories of each star (from Frisch 1993):

Table 1: Nearby Star Astrospheres

HD	Name	Spec	LSR Total Velocity ^(a) (km s ⁻¹)	Long. (deg)	Lat. (deg)	dist (pc)
13421	64 Cet	G0 IV	39	155	-49	30
14412		G5 V	34	214	-70	12
48938		G2 V	35	237	-13	17
50692	37 Gem	G0 V	25	191	13	19
84737	15 LMi	G0 V	26	173	50	13
147513		G5 V	23	342	7	15
181655		G8 V	27	70	11	24

^(a) The absolute space velocity of the stars in the LSR (i.e. $(V_x^2 + (V_y^2 + (V_z^2)^{1/2})$), with using a solar apex motion for conversion to the LSR of 16.5 km/s towards $l=53^\circ$, $b=25^\circ$.

Conclusions

The physical properties of external planetary systems must necessarily be highly sensitive to the dynamical interactions of stellar astrospheres with ambient interstellar matter. This sensitivity is demonstrated by spacecraft observations of the best-observed example, the solar heliosphere. The space motions of nearby stars demonstrate that nearby planetary systems will have dramatically variable interplanetary environments, depending on the location of the star and the stellar trajectory relative to nearby interstellar clouds (Fig. 1).

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